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Study on equilibrium moisture sorption characteristics and modeling of Karaya (*Sterculia urens* Roxb.) gum

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Abstract

Background: Karaya gum is heavily acetylated polysaccharide and used for medicinal purposes as a bulk-forming laxative. It is also used in the paper and textile industries as well as food stabilizer. So its moisture sorption behavior study is important. The moisture sorption isotherms of karaya gum were investigated at four experimental temperatures (30, 40, 50 and 60 °C) under the water activities range from 0.10 to 0.95 using static gravimetric method.

Results: Maximum value of equilibrium moisture content (EMC) of karaya gum (39.7%, db) was noted with the set of highest water activity (0.92) at lowest temperature (30 °C) and minimum value of EMC (2.5%, db) with lowest water activity (0.11) at highest temperature (60 °C). The sorption data were fitted with GAB, Iglesias and Chirife, Caurie, Halsey and BET models. The adequacy of the sorption isotherm models were observed statistically using goodness of fit parameters. The well-known GAB model best interpreted the equilibrium data in a satisfactory manner in the test gum. The monolayer moisture content, estimated using GAB model, was found to be 12.66 g/100 g and 7.4 g/100 g gum at 30 °C and 60 °C, respectively. The isosteric heat of sorption was found to be maximum (36.24 kJ/mol) at 5% moisture content (db) of karaya gum.

Conclusion: Moisture sorption behavior of karaya gum was found to be temperature dependent. EMC decreases with the increase in temperature at particular water activity. The sorption behavior of the test gum expressed the typical type-II sigmoid-shaped curve. Isosteric heat of sorption of karaya gum was decreased with the increase in moisture content.

Keywords: Equilibrium moisture content, Karaya gum, Monolayer moisture content, Relative humidity, Water activity

Background

Natural gums are a group of plant products, established primarily due to the disintegration of plant cellulose. This procedure is known as gummosis. Natural gums are bio-polymeric materials composed of complex hetero polysaccharides and proteinaceous materials, in addition to some mineral elements (Phillips and Williams 2000). Gum karaya, also known as Indian tragacanth, is secured by *Sterculia urens* Roxburgh (Family: *Sterculiaceae*). Natural acid polysaccharides from tree gum exudates have achieved notable attention among researchers because of their immense potential application in the food industry, bio-medicine, and material science. Karaya gum is a major non-timber forest product (NTFP) for villagers and farmers to raise their economic conditions. Among the different tree gum polysaccharides, gum karaya is an important partially acetylated natural polysaccharide having a branched structure with a high molecular mass and is grouped under the pectic type of tree gum. It contains approximately 8% acetyl groups and 40% uronic acid residues. Commercial gum karaya holds about 15–30% rhamnose and 13–26% galactose. Due to its suspension

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properties, acid stability, and high viscosity, gum karaya is well suited for maintaining low pH emulsions, such as dressings and sauces. It is mainly utilized as an ingredient in the preparation of denture fixative powders, bulk laxatives, emulsions, lotions, and as a pulp binder in the formation of thin paper-sand suspension properties. In India, the major producing states of gum karaya are Rajasthan, Maharashtra, Chhattisgarh, Gujrat, Orissa, Karnataka, Andhra Pradesh, and Bihar. In Chhattisgarh state, karaya gum trees are commercially grown in the forest areas of Dantewada District.

For food products, moisture sorption isotherms are of great significance in designing and improving the processing operations such as drying, forecasting shelf-life stability, assessing packaging issues, modeling changes in moisture which occur during drying, designing moisture changes that may occur during storage, ingredient mixing predictions etc. A moisture sorption isotherm represents the relationship between the equilibrium moisture content and the equilibrium relative humidity for a food product at a constant temperature and pressure conditions (Kaymak-Ertekin and Gedik 2004). The awareness of the moisture sorption isotherms is significant in performing engineering calculations, particularly concerning forecasting the quality and stability, changes during transportation and storage under humid conditions. Many mathematical models predicting moisture sorption in food or food materials have been developed by Van den Berg and Bruin (1981). Water sorption isotherms are key thermodynamic tools for forecasting the interactions between food components and water. Representation of sorption data with a suitable sorption model could be used as a tool for achieving these designs. Previous researchers have also studied the sorption isotherm behavior of various gums (Panchev et al. 2010; Vishwakarma et al. 2011). The objective of the present study was to determine the moisture sorption isotherms of karaya gum over a temperatures range 30–60 °C and water activity (0.10–0.95). Fitting of sorption data into selected sorption models to find an appropriate model, as well as monolayer moisture content and net isosteric heat of sorption, was also investigated.

Methods

Collection of materials

The exudate karaya (*Sterculia urens* Roxb.) gum samples were collected from the forest area of Dantewada and Bastar Districts of Chhattisgarh under the Network Project on Harvesting, Processing, and Value Addition of Natural Resin and Gums, which is operated by Indira Gandhi Krishi Vishwavidyala (IGKV), Raipur (Chhattisgarh).

Sample preparation

Karaya gum samples were dried under the sun drying method and a proper cleaning operation was performed before the study of sorption characteristics (Fig. 1). The cleaned test gum samples were grinded and converted into uniform fine particles. To attain this, the gum samples were grounded with the help of a laboratory crusher and passed through a sieve BSS-16 (width of aperture = 1 mm) and retained on BSS-22 (width of aperture = 0.71 mm). The uniform sizes of samples were used for the sorption study.

Procedure and equipment applied for sorption isotherm

Moisture sorption isotherms of karaya gum samples were determined using a static gravimetric technique (Lazou and Krokida 2011; Sahu et al. 2021). The sample was exposed to the humid atmosphere in the container maintained by the saturated salt slurries. The water activities (a_w) of saturated salt solutions were acquired from the data presented by Greenspan (1977) and Labuza (1984). Saturated salts made from pre-decided laboratory reagent grade salts were used in the study to retain different water activity (0.10–0.95) as shown in Table 1. The experiment was carried out at four different temperatures, namely 30, 40, 50 and 60 °C. Saturated salt solutions were prepared in the distilled water at 100 °C, followed by cooling to the desired temperatures for crystallization and placed in the desiccators. Saturated salt solutions with excess salts gave the required ERH or water activity environments inside the desiccators and to compensate possible solution dilution by the liberation of moisture from samples (Igathinathane et al. 2005). Before placing the test samples for actual study, the desiccators filled

Fig. 1 Dried and cleaned karaya gum sample

Table 1 Salts and its equilibrium relative humidity at different temperatures

S. no.	Salts with chemical formula	Equilibrium relative humidity (%)			
		30 °C	40 °C	50 °C	60 °C
1	Lithium Chloride (LiCl)	11.28	11.21	11.40	10.95
2	Potassium Fluoride (KF)	–	22.68	20.80	20.77
3	Potassium Acetate (CH_3CO_2K)	21.61	–	31.40	–
4	Magnesium Chloride ($MgCl_2$)	32.44	32.70	–	29.26
5	Potassium Carbonate (K_2CO_3)	43.17	–	–	37.70
6	Magnesium Nitrate ($Mg\ (NO_3)_2$)	51.40	48.42	46.30	47.70
7	Cobalt Chloride ($COCl_2$)	–	55.48	50.01	–
8	Sodium Nitrite ($NaNO_2$)	63.00	–	–	–
9	Potassium Iodide (KI)	–	66.09	64.49	63.11
10	Sodium Nitrate ($NaNO_3$)	–	–	–	67.35
11	Sodium Chloride (NaCl)	75.00	74.68	74.70	–
12	Potassium Chloride (KCl)	83.62	82.32	–	80.25
13	Potassium Nitrate (KNO_3)	92.31	89.03	85.00	–
14	Potassium Sulphate (K_2SO_4)	–	–	95.80	95.82

with saturated salt solution were equilibrated at respective temperatures for 4 days using BOD incubator.

The gum samples (2.5 ± 0.5 g) were taken in sterilized bottles and placed inside the pre-prepared desiccators, which maintain different water activity conditions. Desiccators were placed carefully inside the BOD incubator to equilibrate samples over the period. The samples were allowed to equilibrate until there was no discemible weight change (± 0.001 g). The weight of each of the samples was recorded at an interval of 3–4 days until the difference between two consecutive readings was negligible. The effect of temperature on the water activity of karaya gum was calculated by comparing moisture loss or gain from the sample inside the sorbostats at different water activities and at corresponding temperatures. The moisture content in the samples during this study was determined as per the method adopted by Sahu and Patel (2020).

The graph plotted between equilibrium moisture content (EMC) versus water activity (a_w) at experimental temperature was the indication of the sorption isotherm of karaya gum.

Mathematical modeling of sorption behavior

Various sorption models for moisture sorption behavior of food and agricultural materials exist in order to model the experimental data obtained from the sorption testing. In order to model the experimental data obtained from the sorption experiments were analyzed and fitted on five different mathematical sorption models at four selected temperatures (30, 40, 50 and 60 °C). The isotherm equations of these models are described in Table 2. Nonlinear second-order least square regression analysis method was adopted for fitting in the sorption models. The regression analysis was applied to find out the model parameters by minimizing the residual sum of square under the required water activity conditions (0.10–0.95).

Statistical evaluation

The accuracy or goodness of fit for each of the isotherm models was obtained by applying various statistical coefficients like adjusted R^2, percentage relative deviation modulus (%P), root mean square percentage error (%RMSE) and standard error (SE). The best-fitted model was selected as the one with the highest adjusted R^2 and the least errors (% RMSE and P). To be considered a good fit, the values of % RMSE and % P should be less than 10% (Jena and Das 2012). The equations used to calculate the goodness of fit as suggested by Sahu and Patel (2020) are as follows:

$$\text{Adjusted } R^2 = 1 - \frac{(N-1)\sum_1^N \left(WY - Y'\right)^2}{(N-M)\sum_1^N \left(WY - Y''\right)^2} \quad (1)$$

$$P(\%) = \frac{100}{N}\left[\sum_1^N \left(\frac{Y - Y'}{Y}\right)\right] \quad (2)$$

Table 2 Isotherm models used to describe the sorption behavior of karaya gum

Isotherm model	Mathematical expression	References
GAB (Guggenheun–Anderson–de-Boer)	$M = \frac{M_O C K a_w}{(1-Ka_w)(1-Ka_w+CKa_w)}$	Quirijns et al. (2005)
Hasley	$a_w = \exp\left(\frac{-a}{M^b}\right)$	Halsey (1948)
Iglesias and Chirife	$M = a + b\left(\frac{a_w}{1-a_w}\right)$	Iglesias and Chirife (1982)
Curie	$M = \exp\left(a + ba_w\right)$	Caurie (1970)
BET (Brunauer Emmett and Teller)	$M = \frac{CM_O a_w}{[(1-a_w)+(C-1)(1-a_w)a_w]}$	Brunauer (1938)

M, EMC, % db; a_w, water activity; *a* and *b*, constants; M_o, monolayer moisture content, % db; *C* Guggenheim constant; and *K*, factor correcting for properties of multilayer molecule with respect to the bulk liquid

$$\%\mathrm{RMSE} = \sqrt{\frac{1}{N}\left[\sum_{1}^{N}\left(\frac{Y - Y'}{Y}\right)^2\right]} \times 100 \quad (3)$$

$$\mathrm{SE} = \sqrt{\frac{\sum_{i=1}^{N}(Y - Y')^2}{(N - M - 1)}} \quad (4)$$

where Y Experimental moisture content, %; Y' Predicted moisture content, %; Y'' Mean of experimental EMC, %; W Weightage useful to each data point ($W=1$); N Number of observations; M Number of coefficients.

All the experiments were conducted in three replications to overcome possible errors.

Evaluation of net isosteric heat of sorption

The determination of net isosteric heat of sorption was performed by the application of the generalized Clausius–Clapeyron equation (Eq. 5) as suggested by Labuza (1984).

$$\ln\left(\frac{a_{w_2}}{a_{w_1}}\right) = \frac{q_{st}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \quad (5)$$

where q_{st} Net isosteric heat, kJ/mol; R Universal gas constant (8.314 J/K mol); a_{w_1} Water activity at temperature T_1; a_{w_2} Water activity at temperature T_2.

The Eq. (6) is used to calculate the isosteric heat of sorption (Q_{st})

$$Q_{st} = q_{st} + \Delta H_v \quad (6)$$

where ΔH_v Latent heat of vaporization of pure water.

Results

Attempts were made to demonstrate the critical observations for up to 3 weeks at 50 °C temperature and an experimental range of water activity conditions (Fig. 2). It is well demonstrated that there were no typical changes observed in karaya gum samples during the study. In this research, five sorption models were taken to fit the sorption data as given in Table 2. The moisture sorption isotherm of karaya gum at different experimental temperatures within a water activity range of 0.10–0.95 is presented in Fig. 3. The model parameters of moisture sorption and their goodness of fit constants obtained in this experiment are presented in Table 3. A comparison of experimental and predicted sorption isotherm of karaya gum using the GAB model is depicted in Fig. 4. The monolayer moisture content of karaya gum was found and presented in Table 3.

The variation in monolayer moisture content (M_o) with temperature (T) of karaya gum according to the GAB model is presented in Fig. 5 and it decreases with the

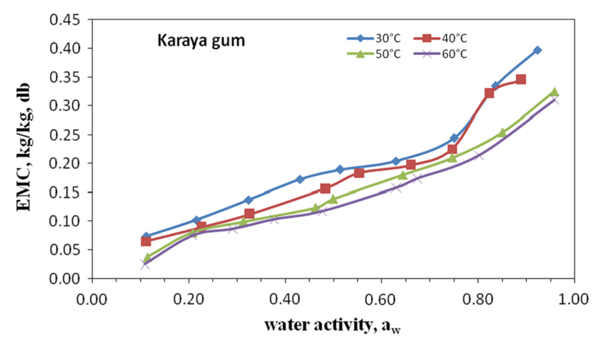

Fig. 3 Sorption isotherms of karaya gum at different temperatures

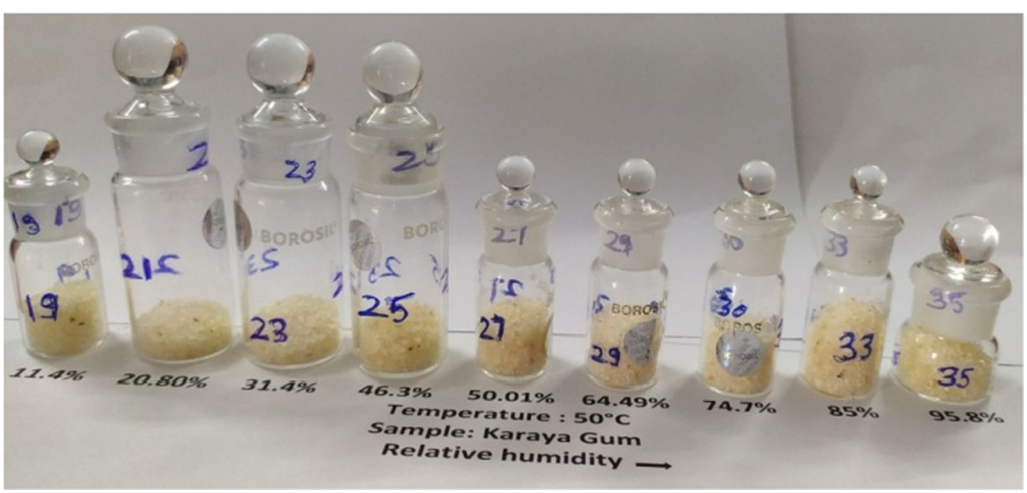

Fig. 2 Karaya gum samples maintained upto 3 weeks at 50 °C and different relative humidity (water activity)

Table 3 Parameters of sorption models and goodness of fit values for experimental temperatures of karaya gum

Model	Temp. (°C)	RMSE (%)	*P* (%)	Adj R^2	SE	Mo	*C*	*K*	*a*	*b*
GAB	30	5.27	0.066	0.978	1.350	12.66	0.008	0.739		
	40	6.69	0.026	0.948	1.897	12.59	0.011	0.701		
	50	10.04	0.073	0.955	1.880	11.50	0.022	0.729		
	60	8.54	0.038	0.971	2.248	7.49	0.028	0.815		
Iglesias and Chirife	30	12.11	2.187	0.972	1.624				7.98	12.89
	40	9.04	1.408	0.967	1.623				5.96	13.46
	50	33.37	9.516	0.892	3.144				6.04	10.00
	60	55.78	19.170	0.845	3.900				4.82	10.34
Caurie	30	21.59	9.431	0.305	0.063				− 1.16	529.8
	40	23.12	9.935	0.393	0.057				− 1.25	514.4
	50	24.86	10.710	0.439	0.059				− 1.24	384.4
	60	27.12	12.090	0.410	0.061				− 1.26	334.0
Halsey	30	12.22	0.784	0.911	0.029				5.05	2.037
	40	10.35	0.579	0.927	0.024				6.84	1.768
	50	31.79	4.446	0.529	0.065				3.40	1.897
	60	44.33	7.661	0.182	0.089				4.90	1.622
BET	30	28.76	13.820	0.677	0.026	10.15	15.33			
	40	1.32	0.142	0.998	0.001	8.68	14.16			
	50	34.30	19.530	0.154	0.033	7.16	10.47			
	60	40.37	27.370	0.650	0.046	3.4	4.49			

increase in temperature. The slope of isosters increased with the decrease in moisture content of karaya gum and is represented in Fig. 6. The net isosteric heat of sorption for karaya gum varies with the moisture content and is depicted in Fig. 7.

Discussion

Moisture sorption characteristics of karaya gum

The gum sample was in excellent condition, with no changes in physical state or color observed during the experiment (Fig. 2). This is an interesting observation which can be useful in exploring the nature of karaya gum for food and pharmaceutical applications. This is also useful in describing the characteristics of karaya gum. However, a greater investigation is required to validate the findings and also compare them with other gum exudates.

It can be seen from Fig. 3 that moisture sorption is temperature dependent and EMC decreases with the increase in temperature at fixed water activity condition. The sorption isotherm graphs of karaya gum for all the experimental temperatures were found to be type-II curves. This may be because of the swellable nature of hydrophilic material till it reaches the maximum hydration sites. The similar trends of results have also been described by previous researchers (Vishwakarma et al. 2011; Sahu et al. 2021). The value of EMC increased with the increase in water activity at constant temperature, which may be due to the hydrophilic nature of the starch present in the karaya gum. Similar findings have also been obtained by Silva and Pena (2018) for buriti tree gum and Wani and Kumar (2016) for extrudate developed from corn- and rice-based composite mix incorporated with green pea and fenugreek powder.

Modeling of sorption isotherm

The moisture sorption experimental data were fitted to five different two- and three-parameter models (Table 2). Attempts have been made to fit the moisture sorption data obtained through a series of experiments to selected models. Regression analysis was adopted to obtain the model parameters, keeping in mind that there should be a minimum residual sum of squares for the range of water activities (0.11–0.95). The model constants along with statistical parameters for five models have been shown in Table 3. It can be seen that the GAB model was found to have the best representation of the sorption data as per the values of average grade statistical errors. The range of RMSE and *P* values was calculated to be 5.27–10.04% and 0.026–0.073% in karaya gum for the GAB model. Similar results have also been presented by Torres et al. (2012) for carboxymethyl cellulose, guar, locust bean, tragacanth and xanthan gums and Silva and Pena (2018) for Buriti tree gum. The comparison of experimental and predicted EMC obtained from the GAB model at four experimental temperatures within the water activity range is depicted

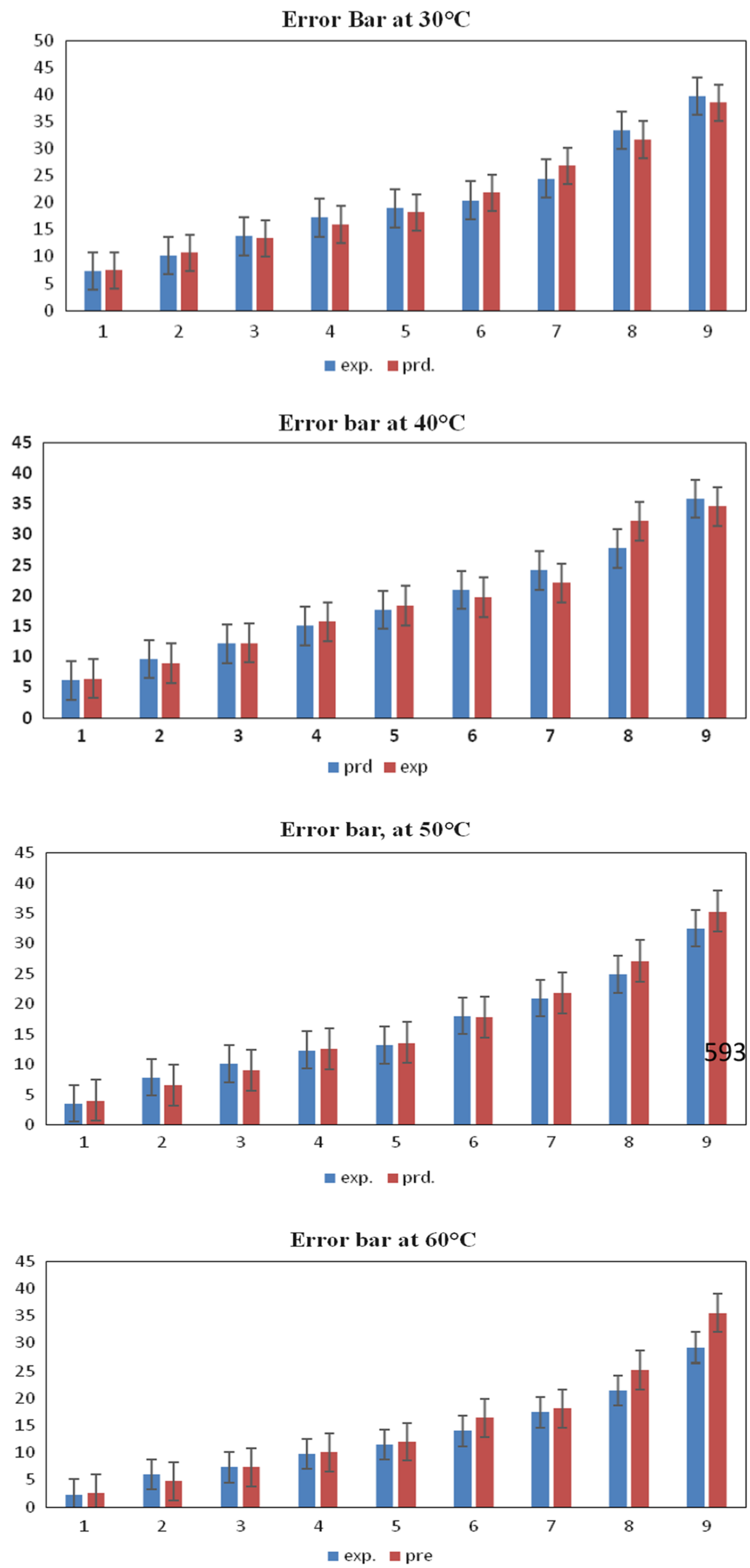

Fig. 4 Comparison of experimental and predicted sorption isotherm of karaya gum using GAB model through error bar

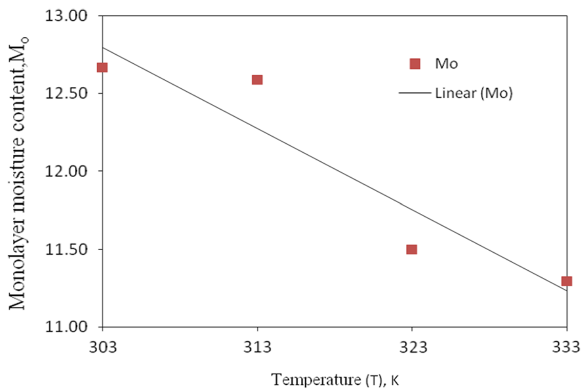

Fig. 5 Variation of monolayer moisture content (M_o) with temperature (T) of karaya gum

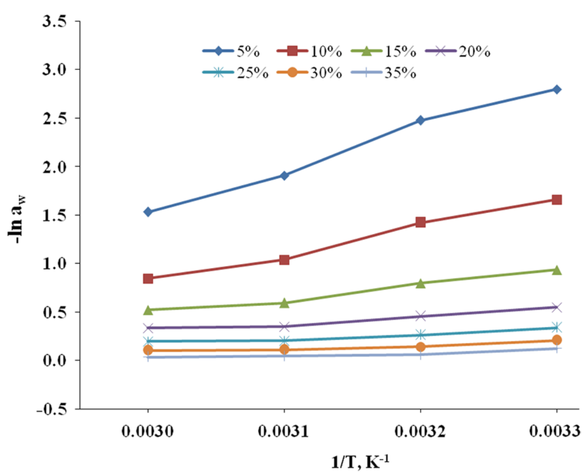

Fig. 6 Sorption isosteres of karaya gum at different moisture content

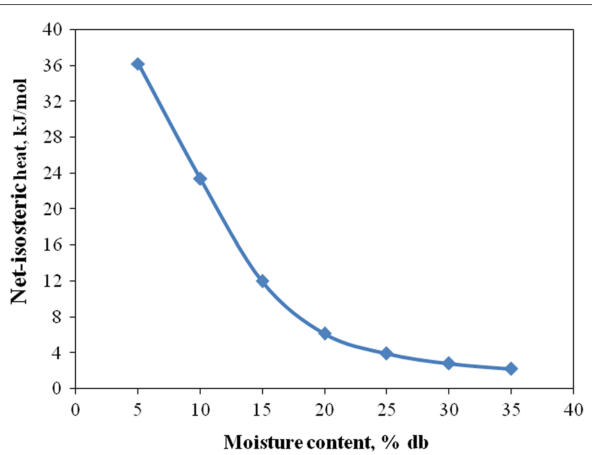

Fig. 7 Variation of net isosteric heat of sorption with moisture content in karaya gum

in error bar graph (Fig. 4). Validation of experimental and predicted EMC value of karaya gum by using GAB model is also presented in Table 4. These error bar graphs at four different temperatures indicate the GAB model is most appropriate to fit the experimental EMC data with least error by comparing the predicted values.

The monolayer moisture content (M_o)

The monolayer moisture content (M_o) is an indicator of the quantity of water that is firmly adsorbed to specific sites at the surface of foods, and this is a value that must be reached in order to satisfy food stability. Below the M_o, the rate of deteriorative reactions is minimal (Choudhury et al. 2011). The BET and GAB models admit the prediction of the monolayer moisture content (M_o) of food products. The monolayer moisture content of karaya gum was noticed to be 12.66 g/100 g and 10.15 g/100 g, respectively, for GAB and BET equations at 30 °C, and their analogous values at 60 °C were 7.49 g/100 g and 3.4 g/100 g, respectively. It is shown in Fig. 5 that the monolayer moisture content decreased with the increase in temperature, which is obvious and similar to many other food and agricultural products. Similar findings in gellan gum (Abramovic and Klofutar 2005) and extruded products (Sahu and Patel 2020) have been reported. This may be due to the fact that the increased temperature causes a reduction in the degree of hydrogen bonding in the polymers, thereby decreasing the availability of active sites for water binding (Mousa et al. 2014). But there is no general agreement among scientists about the effects of temperature on monolayer values. The relationship between monolayer moisture content (M_o) and absolute temperature (T) has also been developed through regression of the data. The following linear relationship (Eq. 7) was established with a high value of coefficient of determination ($R^2 = 0.88$) which shows the better prediction of monolayer moisture of karaya gum.

$$Y = -0.052x + 28.58 \qquad \left(R^2 = 0.88\right) \tag{7}$$

where Y Monolayer moisture, % db; x Absolute temperature, K.

Isosteric heat of sorption for karaya gum

The application of thermodynamic principles to sorption isotherm data can provide vital information about the energy requirements for the dehydration process, food microstructures, physical phenomena on food surfaces, water properties, and sorption kinetic parameters (Rizvi 2005). The net isosteric heat of sorption is the major thermodynamic indicator used to calculate the binding energy of the forces between water vapour molecules and material. In order to determine the isosteric

Table 4 Predicted and experimental values of equilibrium moisture content of karaya gum by GAB model of moisture sorption

30 °C				40 °C				50 °C				60 °C			
a_w	Pre	Exp	SE	a_w	Pre	Exp	SE	a_w	Pre	Exp	SE	a_w	Pre	Exp	SE
0.112	7.418	7.3 ± 0.20	0.11	0.112	6.119	6.4 ± 0.13	0.08	0.114	4.04	3.5 ± 0.13	0.13	0.109	2.59	2.3 ± 0.10	0.06
0.216	10.696	10.2 ± 0.36	0.21	0.226	9.604	8.9 ± 0.30	0.17	0.208	6.56	7.9 ± 0.21	0.12	0.207	4.784	6.0 ± 0.55	0.32
0.324	13.358	13.7 ± 0.26	0.15	0.327	12.074	12.2 ± 0.17	0.10	0.314	9.08	10.11 ± 0.20	0.12	0.32	7.345	7.3 ± 0.10	0.06
0.431	15.939	17.2 ± 0.10	0.06	0.45	14.982	15.7 ± 0.20	0.12	0.463	12.64	12.4 ± 0.56	0.32	0.43	10.057	9.8 ± 0.15	0.08
0.514	18.129	18.9 ± 0.15	0.09	0.554	17.667	18.3 ± 0.20	0.12	0.500	13.59	13.2 ± 0.27	0.16	0.500	11.999	11.5 ± 0.16	0.09
0.63	21.767	20.4 ± 0.10	0.06	0.66	20.889	19.67 ± 0.10	0.06	0.644	17.86	18 ± 0.13	0.07	0.631	16.406	14.0 ± 0.20	0.12
0.75	26.756	24.4 ± 0.26	0.15	0.746	24.0915	22.05 ± 0.90	0.05	0.747	21.82	21 ± 0.58	0.34	0.673	18.137	17.4 ± 0.46	0.26
0.836	31.637	33.4 ± 0.15	0.09	0.823	27.639	32.1 ± 0.96	0.06	0.850	27.13	24.9 ± 0.63	0.37	0.802	25.101	21.4 ± 0.42	0.24
0.923	38.475	39.7 ± 0.17	0.10	0.95	35.814	34.5 ± 0.45	0.26	0.958	35.34	32.5 ± 0.46	0.27	0.92	35.486	29.2 ± 0.75	0.44

Values are mean of 3 determinations ± standard deviation (SD)

heat of sorption, a plot of the natural logarithm of water activity (a_w) as a function of the inverse of absolute temperature ($1/T$) at particular moisture content was developed, which is known as isoster (Fig. 6). The slope of each isoster is calculated by least square linear regression, and the net isosteric heat of sorption was calculated by using the Clausius–Clapeyron equation (Eq. 5). From the graph, it can be observed that the slop of isosters increased with the decrease in moisture content of the karaya gum sample.

Figure 7 indicates that the variation in net isosteric heat (q_{st}) of sorption occurs with the moisture content and also clearly reveals that q_{st} has a negative dependency on moisture content. This decrease can be qualitatively described by the fact that when moisture content is low, the sorption takes place at the most active sites, which offer the greatest interaction of energy (Quirijns et al. 2005). As the isosteric heat of sorption approaches zero, the impact of the adsorbent on adsorbed molecules becomes insignificant. The maximum and minimum isosteric heats of karaya gum were found to be 36.24 kJ/mol and 2.24 kJ/mol, respectively, at moisture content of 5% (db) and 30% (db). The net isosteric heat of sorption initially decreased sharply up to 20% moisture content (db), beyond which the decrease in net isosteric heat was not appreciable. A similar finding has also been reported by Hassan et al. (2020) for the net isosteric heat of sorption in the sukkari date powder.

The water molecules are firmly bounded in the zone of monolayer to the material, which needs high interaction energy during drying. Sorption occurs on the most active sites at lower moisture content and gives rise to a higher energy of interaction between sorbate and sorption sites (Iglesias and Chirife 1976; McMinn and Magee 2003).

Conclusions

The sorption isotherm of karaya gum was observed like many other food materials. Karaya gum had a maximum value of EMC (39.7%, db) with the set of highest water activity (0.92) at the minimum temperature (30 °C) and a minimum EMC (2.5%, db) with the set of lowest water activity (0.11) at the highest temperature (60 °C). The EMC decreased with the rise in temperature at particular water activity, and the EMC increased with the increase in water activity at fixed temperature condition. The isotherms of karaya gum at four different temperatures (30, 40, 50 and 60 °C) exhibited the type-II curves. The parameters were obtained by fitting sorption data into five different isotherm models along with respective error functions. Based on the values of various error functions obtained like adjusted R^2, P, RMSE and SE, GAB equation was found to be the most suitable in the experimental condition compared to the other four models. Using the GAB model, the monolayer moisture content (M_o) was found to be 12.66 and 7.49% (db) at temperatures of 30 and 60 °C, respectively. Maximum and minimum values of net isosteric heat were found to be 36.24 kJ/mol and 2.24 kJ/mol, respectively, for corresponding moisture content of 5% (db) and 30% (db) for karaya gum.

Abbreviations

EMC: Equilibrium moisture content; GAB: Guggenheim–Anderson–de-Boer; BET: Brunauer Emmett and Teller; BSS: British standard sieve; BOD: Biological oxygen demand; ERH: Equilibrium relative humidity; db: Dry basis.

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Author contributions
SSS conducted experiment, preparation of material, data collection and analysis of data. The first draft of the manuscript was written by SSS and CS and also interpreted the data. SP did the conception and design of the work. All authors commented on previous versions of the manuscript. SP, CS and DK helped in correcting the paper, correction in material and methods section. All authors read and approved the final manuscript.

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The authors declare that the data supporting the findings of this research are available within the article.

Declarations

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Not applicable.

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There is no financial/personal interest or belief that could affect the objective, or if there is stating the source and nature of that potential conflict.

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